DEVELOPMENT OF API GRADE LINEPIPE STEELS AT SAUDI IRON & STEEL COMPANY, HADEED

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ABSTRACT

American Petroleum Institute (API) specifications for line pipes include several steel grades with wide range of mechanical properties and chemical composition. Almost all, large diameter pipes produced in the Kingdom conform to these specifications and the present demand of this market segment reaches to about 300,000 tons annually.

Until recently, all material used in the Kingdom under these specification, was imported from the international market. However with the commissioning of Flat Rolling Facilities at Saudi Iron & steel Company, develop the manufacturing technology for these grades. A comprehensive product-development program was therefore undertaken for commercial production of these grades with high and consistant quality. Under this program, extensive experimental work was carried out to produce the material conforming not only to the API specifications but also the customer specific requirements. Today, Hadeed is able to meet most of the local market requirement of the high strength linepipe material.

Keywords: *Line pipe Steels, High Strength Low Alloy Steels, Alloy Development.*

الملخص

مواصفات المعهد الأمريكي للبترول (*API*) لخطوط الأنابيب تحتوي على عدداً من درجات الفولاذ ذات خصائص ميكانيكية وتركيبات كيميائية معينة. معظم الأنابيب المنتجة في المملكة - ذات القطر الكبير- تتطابق مع تلك المواصفات, والطلب الحالي لتلك السوق وصل إلى ٣٠٠،٠٠٠ طن سنوياً.

بالأمس القريب, كانت جميع المواد المستخدمة والمطابقة لمواصفات (*API*) تستورد من الأسواق الدولية, إلى أن تم البدء في تشغيل مصنع الفولاذ المسطّح التابع للشركة السعودية للحديد والصلب (حديد) والذي فتح المجال لتطوير تقنية صناعة الفولاذ بتلك المواصفات. لذلك فقد تم وضع برنامج شامل لتطوير المنتجات التجارية للفولاذ بتلك المواصفات وبجودة عالية. ومن خلال هذا البرنامج تم القيام بعمل تجارب مكثفة لإنتاج مواد ليست فقط تتطابق مع مواصفات (*API*) بل وأيضا تتطابق مع طلبات الزبائن. واليوم شركة (حديد) قادرة على تلبية معظم طلبات السوق المحلية من مواد خطوط الأنابيب عالية المتانة.

1. INTRODUCTION

Pipelines are an efficient mean of mass transportation of fluids over long distances. Although primarily they were designed for the transportation of basic energy sources like oil and gas, over the years their use has been extended to the transportation of potable and industrial water, chemical products, sewage and to even solid materials like coal and ores [Kalwa, G., et al., 1993].

For higher transportation efficiency, the trend in the pipeline design is to use larger diameters with higher operating pressures. This results in a requirement for steels with high yield and tensile strengths. The operation of pipelines in arctic regions, and/or the transportation of liquid natural gas (LNG) also demand high material toughness at low operating temperatures. A particularly important trend has been the exploitation of sour oils and gas reserves, which has required the development of linepipe steels with resistance to hydrogen-induced cracking (HIC). Thus in addition of higher strength and toughness, the pipeline technologies require improved resistance to corrosion to be met with specific alloy additions and special control over non-metallic inclusions [Llewllyn, D.T., et al, 1992].

Both welded and seamless pipes are used in pipeline construction, but as the welded pipes can be made in larger diameters than the seamless pipes, the high capacity pipelines are essentially made from the welded pipes. Both longitudinal and spirally welded pipes are used in the linepipe industry. The welding operations thus require that the materials should be weldable not only during pipe manufacturing process but also at the pipe laying sites where the control over welding conditions becomes difficult.

All these requirements, over the years, are met through the provision of steels with progressive increase in yield strength, high weldability and sufficient toughness to restrict crack propagation particularly at low operating temperatures. While the selection of appropriate chemical composition is important to meet the requirements, the thermo-mechanical processing helps to achieve the specific property requirements. The bulk of high strength linepipe steels are now supplied in the controlled rolled conditions.

Historically, the finished pipes were imported into the local market. However, with the massive industrial development taken place in the recent past, the pipe manufacturing technologies have also gradually been acquired. These pipe manufacturers initially, used the imported hot rolled coils of different grades as their raw material but now with the commissioning of Flat Rolled Product Facilities, Hadeed has also entered into this market segment as a local supplier of high quality flat products.

The demand of linepipe material is project driven and therefore depends upon the economic conditions of the region. The estimated annual demand of linepipe material in the region is around 300,000 tons that includes the steel of various API grades in different thickness and widths. The state of the art technologies acquired by Hadeed flat rolled product facilities make it able to meet most of the market demand of the linepipe steels.

2. SPECIFICATIONS AND PROPERTY REQUIREMENTS

The most popular document specifying the linepipe material is the American Petroleum Institute (API) standard API 5L [API, 2000] that specifies steel grades with a range of properties that cover both the high test linepipe and spiral weld linepipe steels.

The API specifications were introduced in 1948 and at that time included only one grade X-42 with yield strength of 42 ksi. Since that time higher strength steels have been developed and the specification now include grades up to X80 with the yield strength of 80 ksi. The material specification for various grades included in the specifications is shown in Table I.

These specification give very broad requirements for chemical composition, specifying only the maximum permitted levels of carbon, manganese, sulfur and phosphorus. On the other hand, the customer specifications are much restrictive regarding chemical composition to obtain high levels of toughness and weldability at a specific level of yield strength.

The weldability of the steel is governed by the carbon equivalent value that is calculated by formula proposed by International Institute of Welding (IIW) [Bailly ,N. 1974].

$$C_{eq} = \%C + \frac{\%Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$$

Table I: API Standard Material Requirements [API, 2000].

Grade	Chemical Composition % (max)				Yield Strength psi. (min)	Tensile Strength psi (min)	Elongation % (min).
	C	Mn	S	P			
B	0.22	1.20	0.030	0.030	35,000	60,000	The elongation e is calculated by the following formula $e = \frac{625{,}000\,A^{0.2}}{U^{0.9}}$ where A is the cross sectional area of specimen and U is the minimum specified tensile strength psi.
X42	0.22	1.30	0.030	0.030	42,000	60,000	
X46	0.22	1.40	0.030	0.030	46,000	63,000	
X52	0.22	1.40	0.030	0.030	52,000	66,000	
X56	0.22	1.40	0.030	0.030	56,000	71,000	
X60	0.22	1.40	0.030	0.030	60,000	75,000	
X65	0.22	1.45	0.030	0.030	65,000	77,000	
X70	0.22	1.65	0.030	0.030	70,000	82,000	
X80	0.22	1.85	0.030	0.030	80,000	90,000	

Note: Niobium, vanadium, titanium, or combinations thereof may be used by mutual agreement between customer and the manufacturer.

However there is a general feeling that the IIW formula is not adequate to define the behavior of modern steels with low carbon contents and hence the material cracking parameter Pcm is sometimes preferred [Boniszewski, T., 1965].

$$P_{cm} = \%C + \frac{Si}{30} + \frac{Mn + Cu + Cr}{20} + \frac{Ni}{60} + \frac{Mo}{15} + \frac{V}{10} + (B * 5)$$

As indicated earlier, thermo-mechanical processing of steels has permitted to achieve high strength with low carbon contents and this has contributed greatly to improve the weldability in linepipe steels.

In Saudi Arabia, almost all pipeline systems for oil and gas transport are designed on the basis of Saudi Aramco specifications that are themselves based on the API and ISO requirements. The pipe manufacturers while following the Aramco specifications as a guideline, develop their own input raw material specifications that are even more restrictive to ensure that their finished product always meets the requirement of their end customers. A variety of parameters like yield and tensile strength, yield ratio, elongation, impact values and the fracture toughness behaviors are all covered into these specifications. Restrictions on microstructural features are also frequently made as a part of specification. The most popular grades in linepipe steels in the Kingdom are API 5L-B, X-42, X-52, X-60, X-65 and X-70 grades.

3. STEEL COMPOSITIONS FOR LINEPIPE

The rapid developments in the manufacturing technologies of the steel making and processing has turned the science of alloy development into more or less an art. Every steel producer thus fine tunes the chemical composition and the processing parameters to achieve the required properties. While Fig 1 describes the general guidelines for alloy selection, Table II gives the typical chemical compositions used by various world producers of API steel grades [Otton, J.P., et al., 1975].

Table II: Typical Chemical Compositions used by International Steel Producers [Otton, 1975].

Grade	C%	Si%	Mn%	P%	S%	Ni%	Mo%	Cu%	Nb%	V%	Ti%	B%
X65	0.02	0.14	1.59	0.018	0.003				0.04		0.017	0.001
X65	0.03	0.16	1.61	0.016	0.003	0.17			0.05		0.016	0.001
X65	0.06		1.35	0.025	0.005	0.25		0.33	0.04	0.07		
X70	0.03	0.14	1.91	0.018	0.003				0.05		0.018	0.001
X70	0.08		1.60						0.04	0.07		
X80	0.07		1.65	0.022	0.002		0.22		0.05	0.08		
X80	0.02	0.26	1.95		0.003	0.28	0.31		0.04		0.019	0.001
X80	0.08	0.10	1.50						0.05	0.08		
X80	0.04	0.10	1.60			0.35	0.29		0.06			

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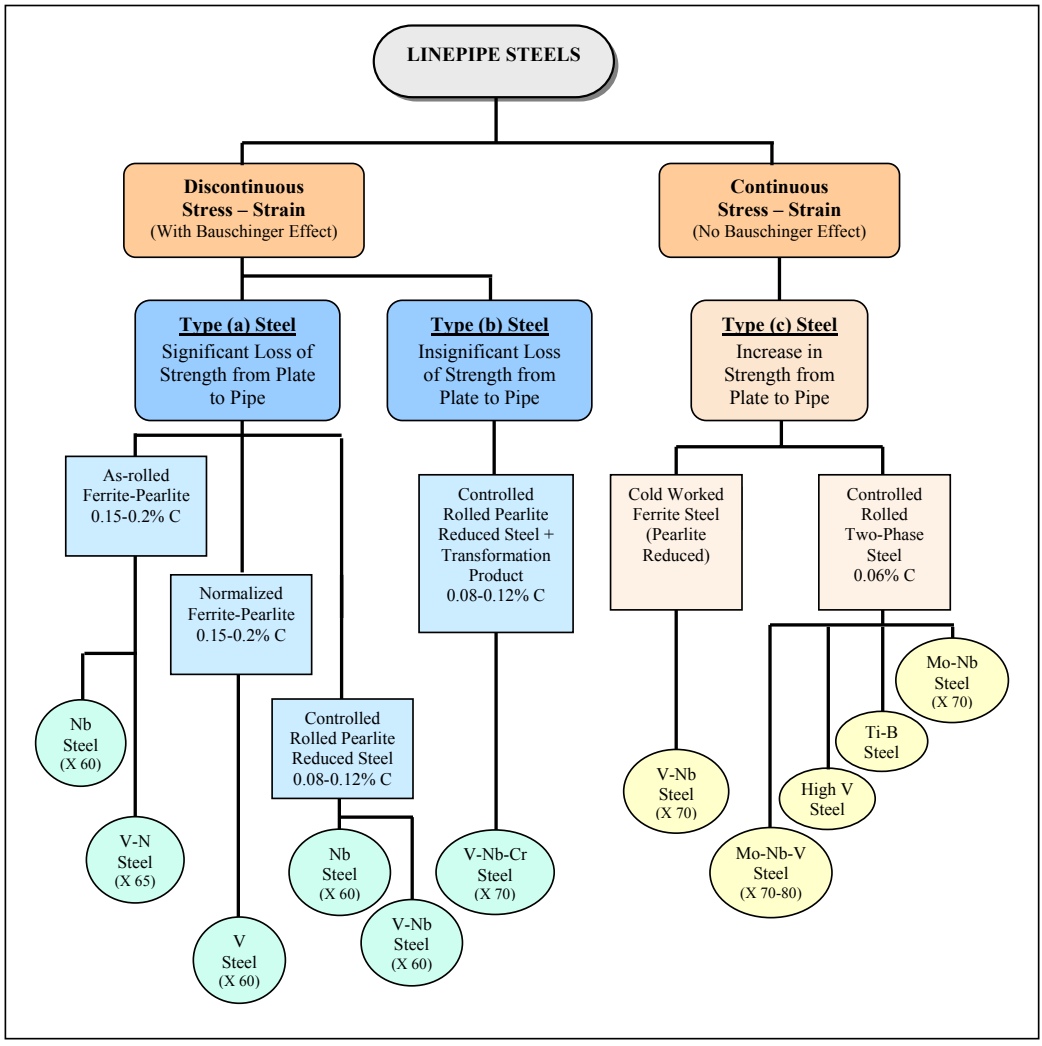

Figure 1: Types of steel used for the production of high strength line pipes.

4. API STEEL PRODUCT DEVELOPMENT PROCESS AT HADEED

The product development process at Hadeed starts with the reciept of customer specifications. These specifications are compared with the existing internal material qualities, to see whether any of the product matches with customer specifications. If the experience is available for the given product, it is included in the production plans and produced through the normal production channels.

However, the products that are either new to Hadeed's production line or have non standard specifications go through the plant trial process. Before the decision on the industrial trial is made, extensive research work is carried out to define the suitable chemical composition and to identify the operating parameters that may control the material properties and structural integrity. The trial documetnts are prepared accordingly and the concerned departments are notified to incorporate the suggestions in the process control computers in preparation for the industrial trial.

If the trial production meets the requirements, the material is dispatched to the customers on trial basis to have their processing feedback. Otherwise, the required changes are made into the process parameters to finetune the required properties and other characteristics. Once the product passes all the required parameters it is considered as a developed product and can be committed to the customers.

Under continual product improvment program, customer feed back is obtained regularly on the product performance for any other required fine-tuning. The product development loop used at Hadeed is shown in Fig 2.

5. RESULTS OF API GRADE DEVELOPMENT PROGRAM

Over the last two years, Hadeed has successfully developed the API Grades B, X-42, X-52, X-60, and X-65. These steel grades as produced in a range of strip thickness conform not only to the standard specifications but also qualify the industrial manufacturing requirements of the customers.

5.1 General Chemical Composition

For lower strength grades like API 5L-B, the normal choice is of C-Mn steels however with increasing strength requirement, especially with limits on the shear area during impact testing, micro alloying by either Nb, Ti, V individually or in combination becomes necessary. The typical chemical compositions used at Hadeed for different grades are shown in Table III.

Table III: Chemical Composition of API Steel Grades Developed at Hadeed

Grade	Chemical Composition %						
	C max	Si max	Mn	Nb	Ti max	V max.	Al max.
X-42	0.12	0.25	1.10- 1.20	0.008-0.015	0.018	----	0.06
X-52	0.12	0.30	1.10-1.35	0.012-0.028	0.020	----	0.06
X-60	0.12	0.35	1.25-1.35	0.045-0.055	0.020	----	0.06
X-65	0.10	0.30	1.25-1.35	0.033-0.038	0.020	0.05	0.06

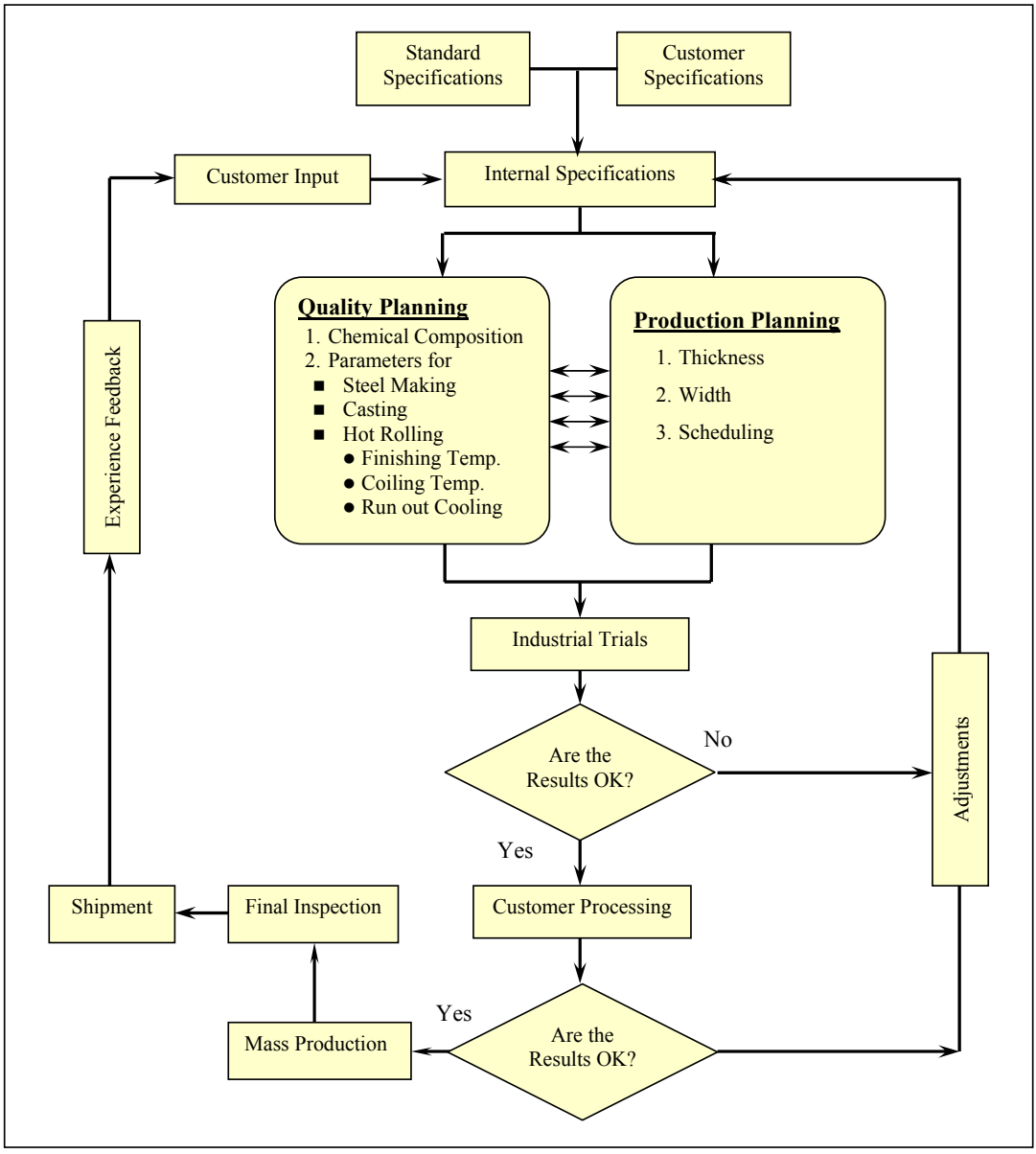

Figure 2. Product Development Loop used at Hadeed for API Steel Grades.

5.2 Carbon Equivalent Values

The API standard specifications limit a maximum carbon equivalent value of 0.42 while customers' specifications limit these parameters to more restrictive levels. The carbon equivalent (Ceq) and cold cracking parameters (Pcm) as required by the customers and those internally specified by Hadeed are compared in Table IV.

Table IV: Comparison of Weldability Parameters for Different API Grades

Grade	Customer		Hadeed	
	C_{eq}	P_{cm}	C_{eq} (max)	P_{cm} (max)
X-42	0.40	0.20	0.32	0.19
X-52	0.40	0.20	0.34	0.19
X-60	0.40	0.20	0.35	0.19
X-65	0.41	0.25	0.33	0.18

It can be seen that the developed chemical composition meet the standard requirements as well as customers specifications in respect of element content, carbon equivalent value and cold cracking parameter (Pcm).

5.3 Mechanical Properties

The controlled rolling technique with effective control of thermal parameters are used to obtain excellent mechanical properties to meet the customer requirements.

The strength of various line pipe steels developed at Hadeed is compared against the standard as well as customer specifications in Table V. It can be seen that the achieved properties are very well placed in the range specified by the customers.

Table V: Strength of Hadeed Steel in comparison with the Specifications.

Grade	API Specifications (min)		Customer Specifications		Hadeed Typical	
	YS (Mpa)	TS (MPa)	YS (MPa)	TS (MPa)	YS (MPa)	TS (MPa)
X-42	290	414	315-486	430-748	400	485
X-52	358	455	360-450	480-580	406	505
X-60	414	517	460-521	555-748	495	589
X-65	448	531	480-570	565-665	506	608

5.4 Customer Feedback

All the products during development stage were monitored under industrial trials at the pipe manufacturing units. The feed back obtained during these trial runs was used to fine-tune the properties to maximize the material utilization at the specific manufacturing unit.

6. CONCLUSION

It is concluded that the professional approach adopted at Saudi Iron and Steel Company, Hadeed, has effectively developed a value-added product of high importance with close control over mechanical properties and chemical composition. These steel grades are successfully being used by the pipe manufacturers to make the line pipes of various diameters for domestic as well international projects.

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